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STATE AND MONITORING OF CARPATIAN NATIONAL PARK TOURIST ROUTES' MICRORELIEF

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Abstract. Recreation is one of the anthropogenic factors of negative impact on the natural environment of the Ukrainian Carpathians and, above all, on the natural complexes of the national parks of the region. In this regard, the Carpathian NPP with a developed recreational infrastructure – a network of tourist routes and stationary recreation areas is an indicative example. Excessive recreational load causes recreational digression and activation of erosion processes on tourist routes. It was established that different tourist routes have different general state of recreational digression and different length of sections with signs of erosion processes. The greatest degradation of natural complexes is characteristic in Chornagora for trails – "To Hoverla Mountain" and "To Lake Nesamovyte", and in Skibovy Gorgany – for the "Dovbush Trail" and part of the route of the trail "To Makovytsia Mountain". On the trail "To Hoverla Mountain" dominate strong and catastrophic V stage of recreational digression (over 90% of the trail's length). On the Dovbush Trail V stage prevails on the slope and transition types of the trail and IV stage of recreational digression prevails on the subhorizontal type of trail. On the path "To Lake Nesamovyte" there is mostly strong and medium degree V stage of digression. On the route "To Makovytsia Mountain" the weak and moderate degree of V stage of digression prevails in the forest belt, on the climb to the top of the mountain with meadow vegetation there is a medium and strong degree of V stage of recreational digression. On the path "Prutu Valley – Maryshevska Ridge – Shpytsi Ridge" prevails the weak grade of V stage. On the trail "Prypir – Zaroslyak" there is a gradual transition of separate sections from the V to the IV and III stages of recreational digression due to the sharp decrease in the recreational load.

Monitoring of the microrelief state of four routes using erosion groove measurement method for 46 cross-sections shows that among the key sections with subhorizontal relief the smallest changes were for the path on the forest weather site of the Chernogorsk Geographical Station of the Ivan Franko LNU, the watershed and valleyside parts of the trail "Prypir – Zaroslyak". The largest changes were monitored for the micro-relief of the path "To Hoverlu Mountain". Among the slope parts of the key areas, the maximum groove (58–73 cm) was recorded above the forest boundary of the route to "To Hoverla Mountain". In the forest zone this value does not exceed 16 cm. A large number of outcrops of massive sandstones caused minimal changes in the microrelief of the slopes of the route in key sections of the Dovbush Trail, and the dense root system of trees contributes to the accumulation of washed material.

The analysis of signs of erosion and denudation processes on the routes shows that the main reason for their occurrence is the excess of anthropogenic loading during massive climbing to the top of Hoverla in combination with rainy periods and the conformity of the trail to relief elements with different steepness. During the comfortable period (May – September) the trail "To Hoverla Mountain" is visited by 94.1% of the annually recorded number of vacationers. The greatest changes in the microrelief of the trails occurred after three rainy periods with increased duration (3, 5 and 12 days) and rains during summer of 2008, which caused a catastrophic flood in the Ukrainian Carpathians. Significant intensification of erosion processes on tourist trails was noted in the summer of 2010 and 2013 as a result of long (10–20 days) rainy periods. The effect of

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vegetation cover is manifested in the width and branching and formation of parallel trails. The widest tourist routes are in the belt of high mountain meadows, the narrowest – within the krummholz. The complex of organizational, management and engineering measures is proposed, which will allow to bring all investigated trails to proper operational condition and minimize the signs of erosion processes.

***Keywords*:** microrelief; erosion process; recreation digression; Carpatian national nature park.

СТАН І МОНІТОРИНГ МІКРОРЕЛЬЄФУ ТУРИСТИЧНИХ МАРШРУТІВ КАРПАТСЬКОГО НАЦІОНАЛЬНОГО ПРИРОДНОГО ПАРКУ

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Анотація. Рекреація є одним із антропогенних чинників негативного впливу на природне середовище Українських Карпат, передусім на природні комплекси національних парків регіону. Показовий у цьому плані – Карпатський НПП із розвинутою рекреаційною інфраструктурою, яка налічує мережу туристичних маршрутів і ділянок стаціонарної рекреації. Надмірне рекреаційне навантаження спричиняє прояв рекреаційної дигресії та активізацію ерозійних процесів на туристичних маршрутах. З'ясовано, що різні туристичні маршрути відрізняються загальним станом рекреаційної дигресії та довжиною відтинків з проявом ерозійних процесів. Найбільша деградація природних комплексів характерна у Чорногорі для стежок "На гору Говерлу" та "На озеро Несамовите", а в Скибових Ґорґанах – для "Стежки Довбуша" і частини траси стежки "На гору Маковиця". На стежці "На гору Говерлу" домінують сильний і катастрофічний ступені V стадії рекреаційної дигресії (понад 90 % довжини стежки). На "Стежці Довбуша" на схиловому і перехідному типах траси стежки переважає V стадія, на субгоризонтальному типі траси – IV стадія рекреаційної дигресії. На стежці "На озеро Несамовите" спостерігається переважно сильний та середній ступені V стадії дигресії. На маршруті "На гору Маковиця" у лісовому поясі переважає слабкий та помірний ступені V стадії дигресії, на підйомі на вершину гори з лучною рослинністю спостерігається середній і сильний ступені V стадії рекреаційної дигресії. На стежці "Долина Пруту – хребет Маришевська – хребет Шпиці" переважає слабкий ступінь V стадії рекреаційної дигресії. На стежці "Припір – Зарослякˮ спостерігається поступовий перехід окремих ділянок з V до IV і III стадій рекреаційної дигресії унаслідок різкого зменшення рекреаційного навантаження.

Моніторинг стану мікрорельєфу чотирьох маршрутів методом вимірювання ерозійних врізів на 46-ти поперечних перерізах засвідчує, що найменших змін серед ключових ділянок субгоризонтального типу зазнали стежка на лісовому метеомайданчику Чорногірського географічного стаціонару ЛНУ імені Івана Франка, вододільні та придолинні частини стежки "Припір – Зарослякˮ, а найбільших – мікрорельєф стежки "На гору Говерлу". Серед схилових частин ключових ділянок максимальний вріз (58–73 см) зафіксовано вище межі лісу на маршруті "На Говерлу". У лісовому поясі цей показник не перевищує 16 см. Велика кількість виходів масивних пісковиків зумовила мінімальні зміни мікрорельєфу схилових відтинків маршруту на ключових ділянках "Стежки Довбуша", а густа коренева система дерев сприяє акумуляції змитого матеріалу.

Результати аналізу прояву ерозійно-денудаційних процесів на трасах маршрутів засвідчують, що головною причиною їхньої активізації є перевищення норм антропогенних навантажень під час масових сходжень на вершину Говерли у поєднанні з дощовими періодами та приуроченістю стежки до елементів рельєфу з різною крутістю. Упродовж комфортного періоду (травень–вересень) стежку "На гору Говерлу" відвідує 94,1 % річної облікованої кількості рекреантів. Найбільші зміни мікрорельєфу стежок відбулися після трьох наростаючих за тривалістю (3, 5 та 12 днів) і кількістю опадів

дощових періодів влітку 2008 року, що спричинили катастрофічний паводок в Українських Карпатах. Значну активізацію ерозійних процесів на туристичних стежках відстежено влітку 2010 і 2013 років унаслідок тривалих (10–20 днів) дощових періодів. Вплив рослинного покриву проявляється у ширині та розгалуженні/появі паралельних стежок. Найширшими туристичні маршрути є в поясі альпійських луків, найвужчими – у межах субальпійського криволісся. Запропоновано комплекс організаційно-управлінських та інженерних заходів, які даватимуть змогу привести усі досліджувані стежки до належного експлуатаційного стану, мінімізувати прояв ерозійних процесів.

Ключові слова: мікрорельєф; ерозійні процеси; рекреаційна дигресія; Карпатський національний природний парк.

Introduction. The Carpathian recreational region of Ukraine, after the decline during 80s – 90s of the 20th century, is again gaining recreational popularity among Ukrainian and foreign tourists. This is manifested in the development of recreational infrastructure and an increase in the intensity of tourist traffic, primarily in national parks. The following negative phenomena are associated with active tourist activity in recreational regions: environmental pollution (surface water, air, and increased clogging of territories), recreational digression of soil and plant cover on tourist routes, anthropogenic modification of mountain natural complexes as a result of active development of tourist infrastructure, impoverishment of the rural areas traditional landscape due to the building urban character of the (Zinko & Gnatiak 2003; Olive & Marion, 2009; Wimpey & Marion, 2010; Dragovich, 2015; Gnatiak & Zinko, 2015; Fidelus-Orzechowska et al., 2017; Amodio et al., 2019; Ziuzin & Rozhko, 2019; Selesa & Cerdà, 2020).

Due to the influence of anthropogenic loadings and natural conditions, tourist routes gradually lose their valuable recreational properties. As a result, is the number of negative processes are in progress: soil compaction and erosion, trampling and destruction of the forest floor, grass cover, damage to tree roots. In this regard, the Carpathian National Natural Park (NNP), which is the most popular nature reserve among lovers of active recreation in the Ukrainian Carpathians, is indicative example. The park covers areas of the mid-mountain massifs of Skibovy Gorgan and Chornohora and the Vorokhtyano-Putilsky lowlands (Fig. 1). On the territory of the Carpathian NNP more than 40 hiking trails of the tourist, scientific, ecological and educational type, three ski and three water routes with a total length of more than 250 km have been laid. Recreational digression (degradation of natural vegetation and formation of erosive forms of microrelief) is observed on the hiking routes “To Hoverlu mountain”, “To lake Nesamovyte”, “Dovbush trail”, “To Yavirnyk mountain” and others due to excessive recreational load on natural complexes. The Hoverlyan-Chornoghirskyi direction of tourists movement from the upper reaches of the Prut River is characterized by one of the highest indicators within the park, especially in the summer. Between 35,000 and 40,000 people pass through the “Zavoyel” checkpoint of the Carpathian NNP in particular, with a growing trend (Zinko & Gnatiak, 2009).

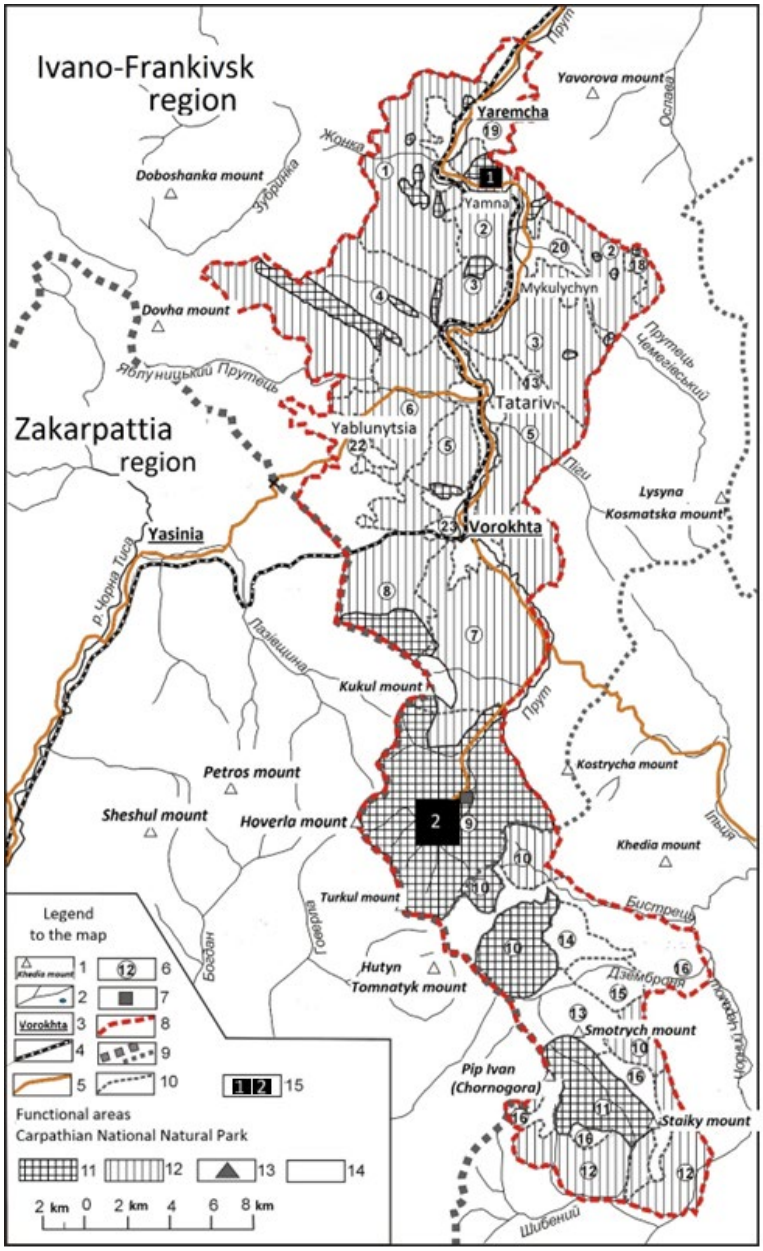

Fig. 1. Location of research zones within the Carpathian NPP
1 – main mountain peaks, their heights above sea level (m); 2 – rivers, streas, lakes; 3 – settlements; 4 – railway; 5 – highway. 6 – nature protection research departments (NPRD) of the Carpathian NPP; 7 – Chornohora geographic stationary (ChGS); 8 – boundaries of the Carpathian NPP; 9 – administrative boundaries (regional, district); 10 – borders of NPRD and settlements; functional zones of CNPP: 11 – protected, 12 – regulated recreation; 13 – stationary recreation, 14 – household, 15 – key loations of research.

NPRD CNPP: 1 – Yaremchanske, 2 – Yamnianske, 3 – Podlisnivske, 4 – Zhenetske, 5 – Tatarivske, 6 – Yablunetske, 7 – Voronenkivske, 8 – Vorohtianske, 9 – Hoverlyanske, 10 – Bystretske, 11 – Chornohirske, 12 – Vysokohirne , 13–23 – lands of settlements.

The topicality of research of the state of the tourist routes microrelief and monitoring of its changes is caused by significant decrease in the recreational attractiveness of certain areas of the park due to excessive recreational load, as well as natural factors (the conformity of the routes to the main elements of the terrain, geological substrate, soil and plant cover and extreme weather phenomena – torrential and prolonged rains).

The purpose of the article is to consider the current state of the microrelief and changes in the surface morphology of popular tourist routes of the Carpathian NNP as a result of the recreational load and certain natural factors in order to develop measures to prevent the manifestation of erosion processes and the deterioration of the recreational attractiveness of the park territory.

Methods and Theory. The analysis of methods for studying the recreational load impact on natural complexes (Gensiruk, et al., 1987; Blaha, 1998; Prędki, 1999; Shlapak, 2003; Komarchuk et al., 2003; Gnatiak, 2006; Brusak, 2018) shows that the main indicator of the recreational load is the soil and plant cover (Brusak & Lenevych, 2020). Its condition and changes due to external influences serve as diagnostic tools of recreational digression stages. In general, the following time series of changes of components of natural complexes is distinguished: vegetation (for meadows) or forest floor (for forests) → soils → relief → geological substrate.

There are five stages of recreational digression, in which various researchers suggest using the following indicators of the state of natural complexes (Gensiruk et al., 1987; Komarchuk et al., 2003; Prędki, 1999; Shlapak, 2003; Lenevych, 2019). This is manifested in a change in the following: the structure of the phytocenosis the thickness and distribution of the forest floor, change in the structure and density of the soil, as well as the width of the trail and the presence of additional/parallel trails. For the IV and V stages of recreational digression it is proposed (Brusak, 2018) to use the indicator "degree of recreational digression" to reflect the manifestation of erosion processes and qualitative changes in the microrelief of the trails. The following levels of recreational degression microrelief were distinguished: "episodic digression" (corresponds to IV stage of recreational degression), "weak digression", "temperate digression", "average degree of digression", "strong degree of digression", "catastrophic degree of digression" (table 1). At the last stages of recreational digression, erosive forms are formed (potholes, gullies, thalwegs of temporary streams) and erosion-denudation processes are accelerated.

Currently, there are no generally accepted methodological developments for the study of changes in the morphology of the surfaces of hiking trails in the recreational areas of the Ukrainian Carpathians under the influence of natural and anthropogenic factors. In separate works (Skvarchevskaya et al., 1986; Zinko & Gnatiak, 2003, 2009) the transformation of the relief surface and the development of various types of microforms under the influence of recreational loads are considered. The basis of microrelief monitoring of tourist routes in this work is methodological developments Lajczak A. (1996a, 1996б) adapted to the conditions of studying the morphodynamics of recreational areas of the Ukrainian Carpathians and combined with semi-stationary

research methods widely used in Ukraine (Zinko & Gnatiak, 2003; Gnatiak, 2006; Gnatiak & Zinko, 2015).

Table 1. Degree of recreational digression microrelief on tourist routes in Carpathian NNP

The stage of recreational degression of the nature complex	The degree of recreational degression of microrelief	The volume of lost material, m^3/m^2	The width of trail's canvas, m	The groove depth of trail's canvas, cm
IV	Episodic degression	0.01–0.025	to 1.5	to 5
V	Weak degression	0.025–0.05	1.5–1.6	5–10
V	Temperate degression	0.05–0.075	1.6–1.75	10–20
V	Average level of degression	0.075–0.1	1.75–2.25	20–30
V	Strong level of degression	0.1–0.25	2.25–2.75	30–50
V	Catastrophic level of degression	0.25–0.5 and more	> 2.75–3.0	> 50

During research of microrelief changes and the erosion signs on tourist trails in Carpation NNP the following methods were used:

1) *establishment of cross-sections for monitoring of changes* in the morphological and morphometric characteristics of the trails and erosion washes, seasonal dynamics and degression directions, as well as and erosion-accumulation processes in key areas of the park. Instrumental measurements have been carried out regularly twice a year (May, September) since 2005 (Gnatiak, Zinko, 2015; Gnatiak, 2009, 2017);

2) *photo fixation of the trails`* condition *from different angles*, which allows to visually record the specifics of the external features of the relief microforms and the signs of erosion processes, tendencies of their combination and distribution. In order to illustrate the scale of the photo image, a system of multi-colored measurement rulers (Fig. 2) was used. The system indicates the types of exogenous processes on geomorphological maps: landslide-loose processes – dark red, linear erosion – orange, planar erosion – light green, suffusion – blue, etc. Contours of erosive microforms were marked with pink rulers and their morphometric parameters were marked with pink lines with white measurement marks (Gnatiak, 2006);

3) *instrumental measurements of transverse profiles along the entire length of tourist trails* in order to calculate the volume of loose material washed away by erosion processes and establish degrees of recreational microrelief digression (Brusak, 2018).

Results. Tourist trails within Skybovi Gorgany and Chornohora were investigated during 2016–2021. These areas belong to the Carpathian NPP territory. Tourist routes "Dovbush trail" and "To Makovytsia mountain" near city Yaremche are located within Skybovi Gorgany. Tourist routes "To Hoverla mountain", "Prypir – Zaroslyak", "To lake Nesamovyte", as well as "Prut valley – Marishevska mountain – Shpitz mountain" are located in Chornohora (Fig. 1). The stages of recreational degression of natural complexes were established, and the width of the trace and the depth of the erosion groove were measured (Brusak, 2018; Brusak & Malets, 2018; Shtuhlynets, 2020; Brusak & Shtuglynets, 2021).

Tourist routes differ in the general state of recreational degression and in the length of segments with the erosion processes signs. Table 1 shows the degradation stages of natural complexes in microrelief of the trails. This approach is used for trails "To Hoverla mountain" and "To lake Nesamovyte" in the Chornohora massif, as well as for "Dovbush trail" and part of route "To Makovytsia mountain" in Skybovi Gorgany.

Fig. 2. The use of measurement rulers on degraded footpath slopes "To Goverla mountain"

The most popular tourist route of the Carpathian NNP is from Zavoelia village to Hoverla mountain (10.5 km). In general, the route includes two trails "Prypir – Zaroslyak" (2.1 km) and "To Hoverla mountain" (3 km), the rest of the route runs along the highway Zavoelia – sportbase Zaroslyak.

On the trail *"Pripyr – Zaroslyak"* mainly moderate (34.6%) and weak (26.3%) degrees of recreational digression with shallow erosive grooves were observed. This is the consequence of the active recreational use of the trail during the 20th century. The current condition of the trail indicates a gradual transition of individual sections from V to IV and to III stages of recreational digression, since the trail is practically not used by recreationists. For this trail self-regulation is possible under the condition of full or gradual reduction of the recreational load.

For the trail *"To Hoverla mountain"* strong (66.6%) and catastrophic (27.7%) degrees of V stage of recreational digressions are prevalent, wichaccount more than 90% of the trail's length (table 2). On the left part of the trail "To Hoverla mountain" (blue marking) there are marked areas with erosion depth up to 1 m. A ravine is formed in a sloping (10–15°) part of the trail between the Mala Hoverla and the upper forest border, which is composed of clay flysh deposits. Our monitoring during 2015–2021 and multiple measurements show that the ravine is growing rapidly (Fig. 3). In the summer of 2015, the largest depth of the ravine was 2.1 m and the width was 1.3 m. In the summer of 2017, the depth of the ravine increased to 2.6 m, with the width up to 3.5 m. In the autumn 2021, the depth of the ravine increased to 3.1 m, with the width up to 3.6 m. During two years the total length of the ravine has increased by 2 times (up to 22 m), in the autumn 2021 it reached 78.7 m (Brusak & Shtuglynets, 2021).

Fig. 3. View of the morphology of the trail of the "To Hoverla mountain" tourist route in 2015 (left) and 2021 (right)

Table 2. Distribution of degrees of recreational digression on tourist routes in Chornohora

The stage of recreational digressionof the nature complex	The degree of microrelief recreational digression	Recreational digression on the trail, %		
		"Prypir – Zarosliak" (Brusak & Malets,2018)	"To Hoverla mountain" (Brusak & Malets,2018)	"To lake Nesamovyte" (Shtuglynets, 2020)
IV	Episodic digression	0	0	5.0
V	Weak digression	26.3	1.77	2.0
V	Temperate digression	34.64	0	14.0
V	Average digression	19.65	3.97	21.0
V	Strong digression	18.63	66.6	51.0
V	Catastrophic digression	0.67	27.66	7.0

On the trail "To lake Nesamovyte" (4 km) predominantly strong (51%) and average (21.3%) degrees of recreational digression with erosion cuts up to 20-30 cmwere observed (Fig. 4).

The tourist trail *"Prut valley – Maryshevska mountain – Shpits mountain"* (6.3 km) is in significantly better condition. The weak degree of V stage of recreational digression prevails on that trail. A moderate degree of digressions on the trail is observed episodically on the steep slopes of the Marishevska and Shpits ridges.

"Dovbush trail" (4 km) extends to the lower part of the Makovytsia mountain slopes (984.5m) on the heights of 540–745m above sea level and is characterized by widespread outcrops of massive Yamna sandstones (Fig. 5). According to the location in relaion to the relief elements on the "Dovbush Trail", sections with sub-horizontal, transitional and slope (longitudinal, transverse and serpentine) types of tracing course were distinguished (Gnatiak, 2004).

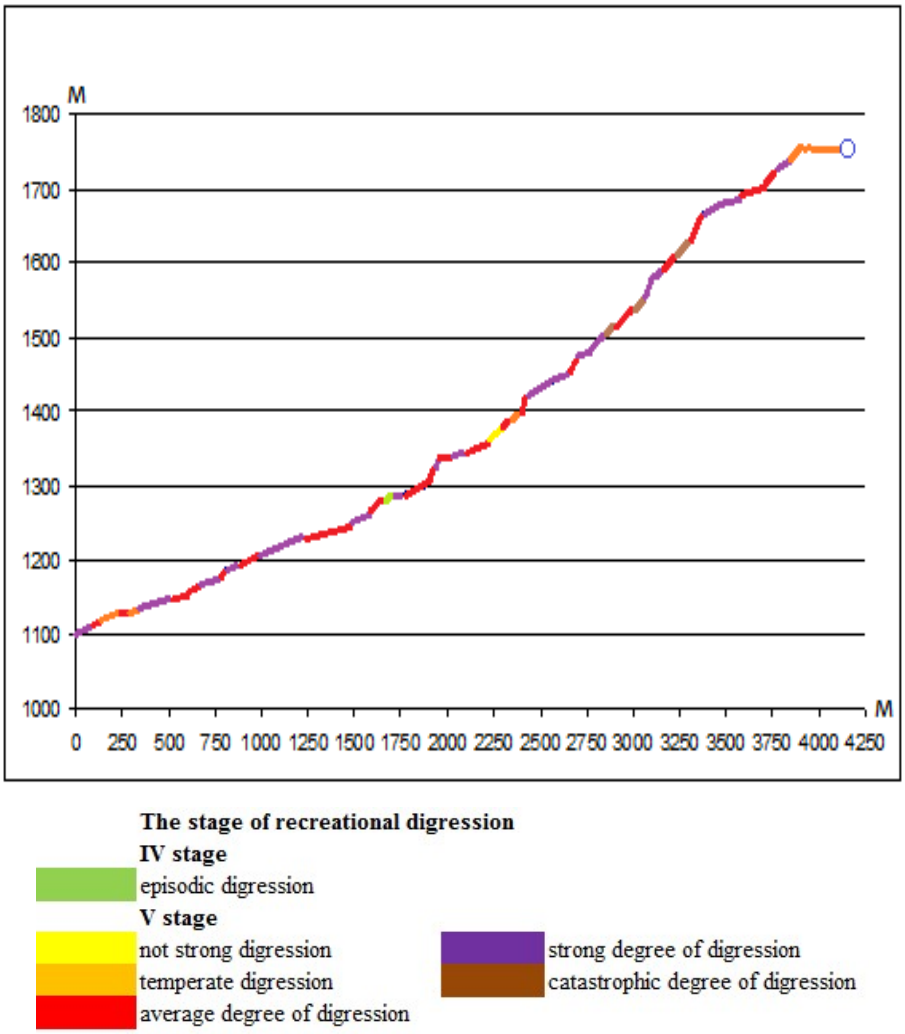

Fig. 4. Longitudinal profile of the state of recreational digression state on trail "To Lake Nesamovyte" (different recreational disgression states are marked with different colors)

Sub-horizontal type of tracing is characterized with the aligned extension, considerable width (2.5–3.5 m) and the presence of a central elevation and two descents on the sides. In the thalwegs of descents rainfall runoff, erosion of sediments and partial cut into the base of the trail are concentrated. On this type of trail section, the IV stage of recreational degression is mainly observed.

The feature of the transition type of the trail is the gradual increase in the steepness and size of the debris, the presence of a central descent with a shallow channel of temporary water flows. Two subtypes are distinguished on the "Dovbush Trail": smooth "cobblestones" and "cobblestones with rubble" (Gnatiak, 2004). The first subtype (500–600 m above the sea level) is characterized by width of 2.5–3 and polished fragments (15–25 cm) of sandstones, which determined the name. On another subtype of the trail (540–560 m above the sea level) accumulative sediments were observed. The width of

the trail is about 3 m and along its sides to the depth of 50–70 cm the soil cover and indigenous rocks are exposed. The channel of the temporary flow meanders along the entire width of the trail. From the height of 560 m, the steep ascent of the trail begins, its width narrows to 1.5–2 m, in some places the trail branches into three tracks due to its adaptation to sandstone outcrops and tree roots. The trail stretches in the form of serpentine across the slope and is characterized by the V stage of recreational degression.

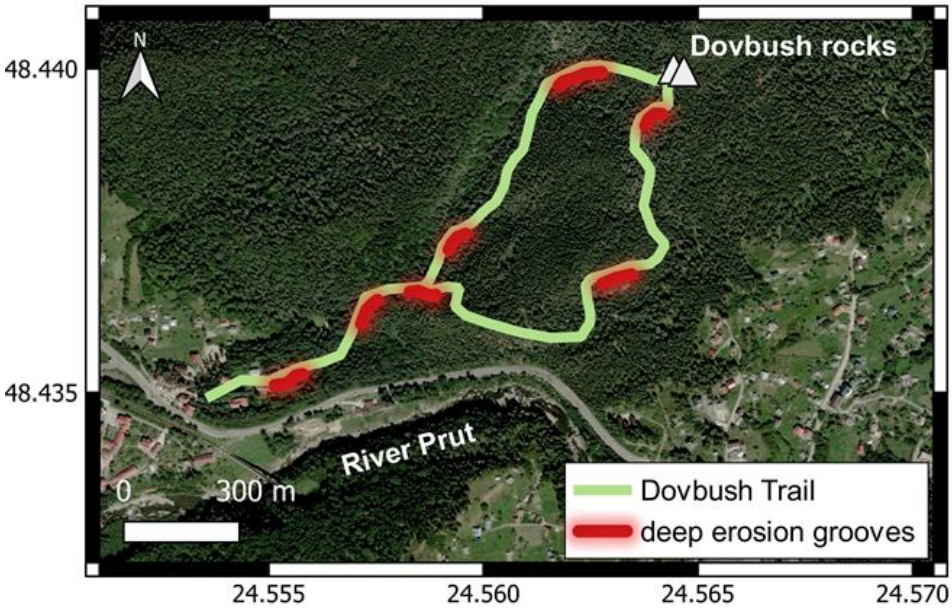

Fig. 5. Location of erosion processes on "Dovbush trail"
(Brusak, Gnatiak & Shtuglynets, 2022)

The longitudinal type (560–625 m and 680–740 m) is characterized by the step-like form of the trail with a stony, root or root-stone edge of the steps. The root-step aspect of the trail is represented by randomly exposed tree roots in the form of separate steps. The platform of the steps with up to 30 cm width is composed of soil with a layer of fine debris and dried conifer, separated by tree roots. In the vertical part of the step, the soil cover and bedrock are exposed. The outer parts of the outcrops of indigenous breeds are polished, devoid of moss or lichens. The width of the trail varies from 70 cm to 2 m, and the height of the steps is 10–25 cm. As the size of the debris increases (from 50 cm to 1–2 m), the number and depth of erosion cuts increase (Gnatiak, 2004).

Transverse and serpentine types of the trail alternate with longitudinal sections along its entire length at heights of 625–675 m and 725–740 m. The width of the trail reaches 0.7–2.5 m. On the upper side can be observed tree roots and sandstone fragments, whereas on the other side kind of bank (with height of 20–30 cm) formated by accumulative material could be indicated. In some places, with a slight ascent or descent, the transverse sections of the trail turn into serpentine ones with no banks. Sharp differences in the steepness of the terrain on the longitudinal and serpentine sections of the trail lead to the formation of erosive landforms. The slope type of the trail is mainly characterized by the V stage of recreational degression (Brusak et al., 2022).

On the tourism trail "*To Makovytsia mountain"* (8 km), three sections are distinguished according to the location relative to the elements: 1) descent valley slopes,

2) alternating sections with steep and descent slopes, 3) steep climb to the top of the mountain of Makovytsia. The beginning of the trail runs along a stone forest trail on a descent slope, which is dominated by V stage of weak and moderate degrees of recreational degression. In the middle part of the trail moderate degree of the V stage of degression is observed. The ascent to the top of the town of Makovytsia mountain runs through a deforested area, where there is medium and strong level of V stage of recreational degression (Brusak et al., 2022).

Monitoring studies of the state of the routes are carried out on the trails "To Hoverla mountain" (14 sections) (Fig. 6), "Dovbush trail" (12 sections), "Prypir – Zaroslyak" (10 sections) and on the trail on the forest meteorological site of the Chornogora Geographical Station (CGS) of the Ivan Franko National University (6 sections). Result of the field measurements include the following: a number of profiles, a set of tabulardata and photos, maps of the initial state and periodic changes. In general, he obtained data makes it possible to outline the predominant factors, influencing changes in the morphology of the trails` surface over a certain period of time.

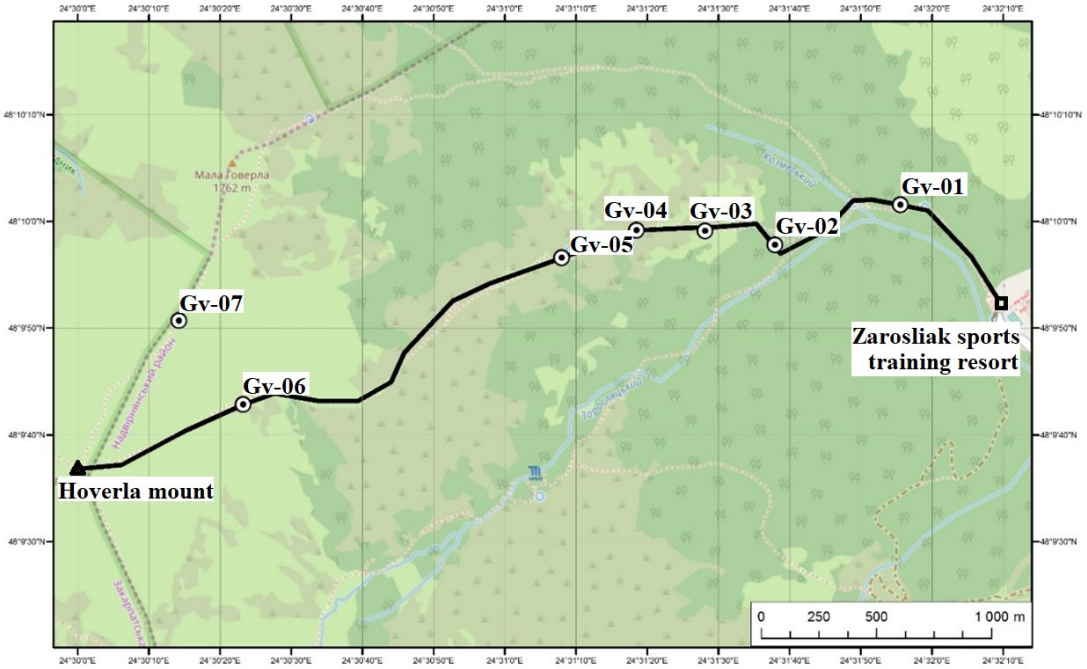

Fig. 6. Location of monitoring areas on the trail "To Hoverla mountain"

During the period of observation (in the article are presented the results of research during 2005–2015), among the key areas with a subhorizontal stretching, the path at the CGS forest meteorological site, the watershed and lower parts of the tourist route "Prypir – Zaroslyak" underwent the smallest changes. The largest changes were indicated for the surfaces of the paths of the tourist route "To Hoverla mountain" (Figs. 7, 8, 9). Intensification of erosion processes on the path of the shorter tourist route with blue and white marking caused an erosion groove of 18–24 cm. Among the slope parts of the key areas, the maximum groove (58–73 cm) was recorded on the open parts of the slope above the border of the forest of the tourist route on "To Hoverla mountain" with blue

and white markings (key section Gv-03). In forested parts, this value did not exceed 16 cm (key section Gv-02).

Fig. 7. General view of trails morphologe of tourist route
“To Goverla mountain” in 2005

Fig. 8. Intensification of erosion on the trail of tourist route
“To Goverla mountain” in 2015

The nature and presence of rock outcrops also have a significant influence on the morphodynamics of trail surfaces (massive Yamnian sandstones caused minimal annual changes in the slopes of key sections of the “Dovbush trail” tourist route). In addition there is the impact of thickness, uncovering, and density of the tree root system (partially uncovered roots with a diameter of 1–2.5 cm contributed to the accumulation of

material). The growth of woody species often adjusts the width and causes pathsdisplacement aside from the original posiion by 25–30 cm.

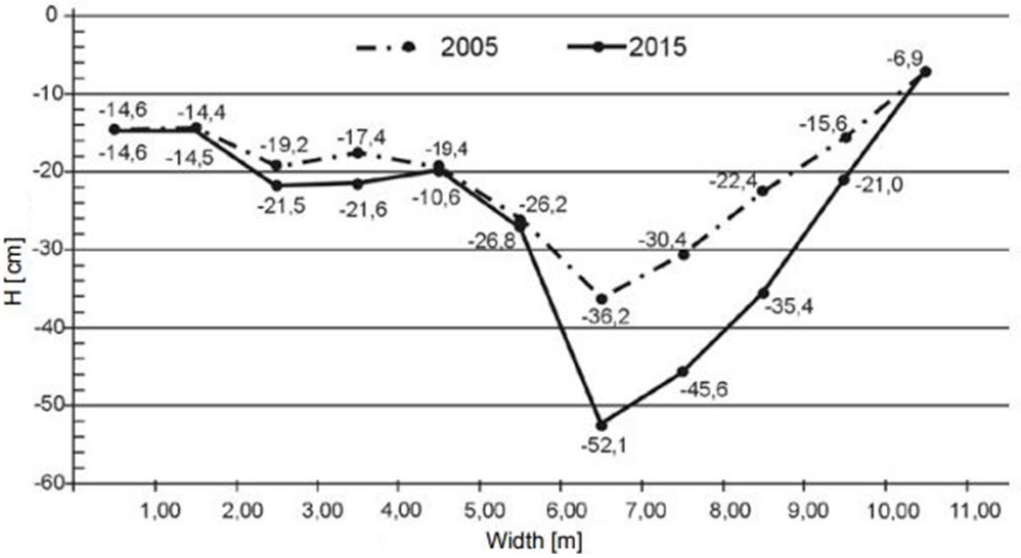

Fig. 9. Changes in the cross-sectional indicators of trail of tourist route “To Goverla mountain” (2005 and 2015) (Gnatiak & Zinko, 2015)

Analysis of signs of erosion-denudation processes on the pedestrian routes shows that one of the main reasons for their formation and development is the excess of anthropogenic loads during mass climbing. The load on natural ecosystems also varies depending on the seasons. In a comfortable period, the peak of Hoverla is visited by 94.1% of the annually recorded number of vacationers (May – 7.8%, June – 15.3%, July – 40.2%, August – 27.7%, September – 3.3%). During another part of the year the number of visitors reaches only5.9%of the annually recorded amount.

Climatic factors contribute to the emergence and activation of exogenous processes, primarily torrential rains, intense snowmelt, morphometric relief indicators, etc.

The archive materials for 2005–2015 from three weather stations located near the key sections of the tourist route “To Hoverla mountain” were analyzed: the Pozhizhevska snow avalanche station, the ChGS weather station of the Ivan Franko Lviv National University, and the mudflow station in the city of Yaremche. The main emphasis was made on the characteristics and features of the regime of atmospheric precipitation and snowmelt, the height of the snow cover and its water reserves (Dudych & Gnatyak, 2012). The impact of the duration of rainy and dry periods, their combination and character (increase or decrease in rainfall amount) on soil over-moistening and, as a result, increase of the transformative properties of trail surfaces was revealed.

In the case of longer rainless period followed by rainy one, the gradual increase in precipitation amounts has lower fluence on transformative properties than the decreasing nature of the rainy period after a one-time fall of large daily precipitation amounts. If there are short rainless periods between longer rainy ones, then the further increase in daily precipitation amounts leads to the waterlogging of hollows on the paths with the subsequent mixing and removal of soil fines. Surfaces adjacent to the existing path are additionally affected and transformed. With the same duration of rainy and non-rainy

periods, precipitation with uniform intensity is optimal of tourist routes from the sustainable functioning point of view.

The amount and distribution of precipitation by hours of the previous day in combination with a significant seasonal recreational load, is another factor contributing to the digression of the soil-vegetation cover and the development of erosion processes. Rainfall between 9 am and 3 pm has the greatest impact on the transformation of trail surfaces and the activation of erosion processes during this period. Average impact – in the time interval from 3 to 7 and from 4 to 7 p.m. (with rainfall up to 20 mm). The presence of precipitation at other times (with a daily amount of no more than 30 mm and a uniform character of rain) does not significantly affect the activation of erosion processes.

Observe that the biggest changes in the morphology of the trail surfaces occurred after the catastrophic flood in the summer of 2008. At the end of June and during July the duration of the three rainy periods increased (3, 5 and 12 days), the amount of precipitation reached its maximum value also in this period (14 mm, 27.4 mm and 275.3 mm for CGS). As a result, the combination of significant waterlogging formed in the previous months and extreme fainfall, which caused the intensification of erosion processes on tourist routes.

Average changes in the trails morphology were noted in 2010 and 2013. Long rainy periods (from 10 to 20 days) were observed in mid-June until the end of July 2010, while the dry ones were rather short (1–2 days). Rainfalls occurred mainly at night and ware average in intensity. In mid-May untill the end of June 2013, there were several long (up to 15 days) and significant rainfall periods, which began after a 10-day rainless period with a heavy downpour.

The influence of vegetation cover was manifested primarily in the width and branching/appearance of parallel paths. On the tourist route “To Hoverla mountain” in the forest belt the width of the path does not exceed 4–5.5 m. There is a branching of the trails around the trees. In the meandering forest belt, the width of the paths narrows to 2.5–3.5 m due to the difficult passability of the territory. Sometimes there are sections with a width of 6 m due to the merging of parallel paths. In the belt of high-altitude meadows (polonyns), the paths extend up to 6 m. Parallel paths formation is often observed.

A significant influence on the components of the natural environment and manifestations of recreational digression has the ratio of different shades of tourist routes to landforms. Accordingly, we distinguish the following types of sections of trails: subhorizontal, transitional and slope (longitudinal, transverse and serpentine). The specifics of the movement of groups of recreationists on the route also have a certain influence: movement in a column or in pairs, ascent or descent of the group, the orientation of the feet of each recreationist depending on the steepness of the slope, the distribution of body weight and the inclination of the body, as well as the running of cattle and sheep along tourist trails. The preparation and current repair of the equipped trails affects the ecological condition of the routes.

The greatest influence of relief morphology on the transformation of the microrelief of tourist routes was recorded on the slope surfaces of mountainous and upland dissected relief. The experience of studying the recreational digression of tourist routes on the slope areas in the Carpathian NNP made it possible to distinguish a certain stage in the transformation of the microrelief as a result of the tourist loading. These stages can be

identified by a specific combination of microrelief of the recreational-tourist and erosion-denudation type, an additional feature is the state of the soil and vegetation cover (Zinko, Gnatiak, 2003). The stages of relief transformation at the same time reflect the nature and direction of mechanical deformation of the surface under the action of various types of tourist loadings, as well as the role of natural and anthropogenic slope processes, vegetation and geological substrate in the formation of microrelief on tourist trails.

In general, *four stages* of transformation of the microrelief of tourist routes on the slopes under pedestrian loading could be distinguished: 1) *initial* with locally developed microrelief of mechanical deformation, 2) *embryonic* with primary microforms of pedestrian surface transformation (microhollows, ruts), 3) *mature* with characteristic microforms of pedestrian tourism, modeled by slope processes, the structure of the tree stand and geological substrate, 4) *the final stage* with pronounced forms of erosion-denudation degradation of trails.

At the same time, each of the stages of the relief transformation is identified by the state of the soil-vegetation cover and the exposure of the original geological substrate (Zinko & Gnatiak, 2003).

Discussion and recommendations. Based on the analysis of the duration of rainy and dry periods, their nature (precipitation increasing or decreasing), amount and distribution of precipitation by hours during the previous day, a draft recommendation matrix was developed for the administration of the Carpathian National Park on the admission or partial restriction (hours, days) of visitors on tourist sites routes. We suggest to use the matrix for the summer period and unequipped routes. The developed matrix is supplemented with indicators of changes in the height of the snow cover per day and a complex characteristic of thawing for the autumn-spring period.

It is proposed to improve the registration of visitors to each tourist route of the Hoverla NPRD of the Carpathian NNP instead of the existing recording of the total number of visitors at the “Zavoel” checkpoint of the national park.

Based on the current ecological state of tourist routes we recommend to use of bottom and trail engineering microstructures for reducing the speed of water flow along the bottom of potholes or trail beds to acceptable limits, increase the stability of their slopes and delay sediments (Gnatiak, 2018). Since the main role in the formation of the microrelief of footpaths is played by the soil-vegetation cover (especially the roots of trees) and the geological substrate (including detrital material), the implementation of engineering recommendations should, first of all, be based on the availability and characteristics of local materials.

The most appropriate micro-engineering structures that will reduce the energy of the water flow and redistribute it on the routes of tourist routes are: 1) wooden steps consist of thin fir trunks, thick branches or tree roots; 2) steps from available natural stones (sandstones); 3) micro-stepped stony gradients in the channels of temporary watercourses. Thin spruce trunks and large sandstone fragments can be used for arranging tourist routes in the forest belt. Natural stone fragments can be used for arranging tourist routes above the upper forest boundary. It is appropriate to divide tourist pathes into segments according to their location relative to relief elements (Gnatiak, 2004) and to outline the types of engineering fortifications for each type of trail: 1) steps on slope types of trails (longitudinal and serpentine); 2) micro-graded drops on sub-horizontal sections of trails.

Conclusions. Excessive recreational loading causes the manifestation of recreational digression and activation of erosion processes on the tourist routes of the Carpathian NNP. Insufficient development and imperfection of research methods for changes in the tourist routes microrelief and the intensity of erosion-denudation processes determines the need for further study of this issue and conduct of special field research. The development of indicators for assessing the state of natural complexes along tourist routes and recommendations for preventing the intensification of erosion processes on the most popular tourist trails of the park remains relevant.

The character of a recreational degression and its dynamics for two trails "To Hoverla mountain" and "Dovbush trail" in different parts of national park shows that the condition of the pathes could not be improved in a natural way. In the article are proposed special organizational, management and engineering measures, which will allow to bring all investigated trails to proper operational condition.

Organizational and management measures could include: 1) restoration of the practice of annual trails duty to the Hoverla mount. This will allow the partial recovering in a natural way; 2) forbidness of climbing of large groups to Hoverla in May, when the soil on the slopes is saturated with melt-water and has the least resistance to recreational loading; 3) increasing the entrance fee to the Carpathian NNP, which may partially reduce the flow of tourists; 4) limiting of number of tourists on holidays in trails "To Hoverla mountain", "To Makovytsia Mountain" as well as "Dovbush trail".

There is a couple of necessary engineering measures: 1) the improvement of the trail in the vicinity of Zarosliak sports base (covering of the trail with natural stones, lining the canvas path with gravel); 2) organization of a system of limiting handrails for all the trails within the forest belt and pavement steps which are of natural stone on the canvas path on slopes with a steepness up to 20°; 3) pavement of a system of stone steps and limitation of the path route with handrails on the steep (25–35°) near slopes of Mala Hoverla; 4) tracking zigzag lines along the trail from Mala Hoverla to the top of Hoverla and last part on trail "To Makovytsia mountain".

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